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An advanced gradient histogram and its application for contrast and gradient enhancement ☆

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ABSTRACT

This paper proposes an image contrast and gradient enhancement method based on advanced gradient histogram equalization (AGHE). We first define a novel advanced gradient histogram (AGH). Unlike the traditional intensity histogram which only contains intensity information, the AGH contains both gradient and intensity information of image. This character enables AGH to alleviate high peaks and thus avoid over enhancement in AGHE. Moreover, it's proved that AGHE can increase the mean of absolute gradients (MAG) which is a measurement of image gradient. Then we present a sine function histogram correction (SHC) to control the enhancement level of AGHE. By modifying AGH using SHC before equalization, both the contrast and gradient enhancement levels can be controlled effectively. Simulation results demonstrate that AGHE with SHC (SAGHE) can improve the image subjective quality effectively by enhancing both the contrast and gradient of image.

1. Introduction

The contrast enhancement, as a kind of significant processing technique for both images and videos, can effectively improve the image visual quality for human perception and recognition. In addition, it is also an important preprocessing step to accentuate the essential features in images and videos for automatic pattern recognition, machine vision and other applications.

Various contrast-enhancement techniques have been developed. Histogram equalization (HE) is a widely used global enhancement method. Since the contrast gain is proportional to the height of the histogram, gray levels with larger pixel populations are expanded to a larger range of gray levels, whereas other gray-level ranges with fewer pixels are compressed to smaller ranges. Although HE can efficiently utilize display intensities, it tends to over enhance the image contrast if there are high peaks in the histogram, often resulting in a harsh and noisy appearance of the output image [1]. Numerous other global histogram equalization (GHE) methods have been proposed for limiting the level of enhancement, most of which are obtained through modifications on HE such as mean preserving bihistogram equalization (BBHE), brightness preserving histogram equalization with maximum entropy (BPHEME) and weighted thresholded HE (WTHE) [2–8]. These techniques usually outperform the basic HE technique. However, they fail to emphasize details of the local regions because they use histogram information over the whole image [5]. To overcome this limitation, local histogram equalization (LHE) based methods are developed [9,10]. The LHE based methods generally require more computation and they not only highlight details in the image but also enhance noise.

Besides traditional histogram-based methods, there are also unconventional approaches to solve the contrast enhancement problem. Celik and Tjahjadi employ Gaussian mixture modeling (GMM) of an input image to perform nonlinear data mapping for enhancement [11]. The GMM is an automatic method and suitable for different types of images, however, it spends high computation cost. Recently, a contrast enhancement using adaptive gamma correction with weighting distribution (AGCWD) is proposed, which smoothes the fluctuant phenomenon by weighting distribution and enhances image automatically using gamma correction [12]. The AGCWD is straightforward while it may lose details in the bright regions of image when there are high peaks in the input histogram. Multiscale contrast enhancement techniques explore image decomposition before image enhancement to prevent artifacts. These techniques are computationally complex though generally yield high subjective quality [13,14].

Whereas a variety of contrast-enhancement techniques have been proposed to improve the qualities of general images, all of them just utilize the intensity information of image without emphasizing the change of intensity. In fact, the human visual

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system (HVS) is more sensitive to intensity changes, i.e., the gradient than the absolute intensity of image [15–18]. Moreover, the enhancement of gradient is essential in many subsequent applications of image enhancement such as target detection and recognition considering the high gradient pixels to be the edge which is a basic feature of target [19,20]. Our goal in this paper is to develop an image enhancement algorithm, which is capable of enhancing image contrast in general and enhancing the gradient specially. The main contributions of this paper are:

- Propose a novel advanced gradient histogram (AGH). Besides pixel population information of each intensity, AGH contains gradient information of image, which reflects the range of intensity levels at which details of an image occur. Moreover, the peaks of AGH are much lower than those of traditional histogram which only contains intensity information. This can alleviate the over-enhancement phenomenon of enhancement algorithms based on traditional histogram.
- Propose a straightforward and visually pleasing image enhancement method, i.e., SAGHE. To the best of our knowledge, SAGHE is the first image enhancement technique which can enhance both the contrast and gradient of image. The sine function histogram correction (SHC) used to modify AGH before equalization can control the enhancement levels of both contrast and gradient strength effectively using a parameter n.
- Define mean of absolute gradients (MAG) as a measurement of image gradient. Give a universal expression of MAG of enhanced images using GHE techniques and further prove that the theoretical maximum value of MAG of GHE techniques can be achieved using our SAGHE with $n = -\infty$ in SHC.

The rest of this paper is organized as follows: Section 2 presents a detailed description of the proposed AGH. Section 3 proposes the novel image enhancement method SAGHE. Section 4 presents experimental results. Finally, Section 5 concludes this paper.

2. The advanced gradient histogram

In this section, we first give the definition of the mean of absolute gradients (MAG) and then give a detailed description of the proposed advanced gradient histogram (AGH).

2.1. The MAG

The purpose of this paper is to propose an image enhancement method which can not only enhance the image's contrast in common sense but also strengthen the gradient of image specially. In order to measure the gradient strength of the whole image, the mean of absolute gradients (MAG) is adopted in our paper and can be calculated simply using the following expression

$$MAG = \frac{1}{2MN}\sum_{i=2}^{M-1}\sum_{j=2}^{N-1}(|G_x(i,j)| + |G_y(i,j)|) \tag{1}$$

where $M \times N$ is the size of input image $f_{M\times N}$. G_x and G_y are the gradient in the x and y directions, i.e.,

$$\begin{aligned} G_x(i,j) &= f(i,j+1) - f(i,j-1) \\ G_y(i,j) &= f(i+1,j) - f(i-1,j) \end{aligned} \tag{2}$$

where $i = 1,2,\ldots,M, j = 1,2,\ldots,N$ and $f(i,j)$ presents the intensity at location (i,j).

2.2. The AGH

Histogram can be used in many image processing techniques such as enhancement, compression and segmentation. The traditional intensity histogram shows the occurrence frequency of each gray in the image [1]. In this part, we define a novel histogram named AGH, which can give the information about the gradient of an image.

In order to introduce this new histogram, the scalars $G_x(i,j)$ and $G_y(i,j)$ are represented by two gradient vectors $GV^x_{(i,j)}$ and $GV^y_{(i,j)}$ respectively. Both of them are of size $1 \times L$, the k_{th} element of which can be defined as follows

$$\begin{aligned} GV^x_{(i,j)}(k) &= \begin{cases} 1 & k \in [f^x_{\min}+1, f^x_{\max}] \\ 0 & else \end{cases} \\ GV^y_{(i,j)}(k) &= \begin{cases} 1 & k \in [f^y_{\min}+1, f^y_{\max}] \\ 0 & else \end{cases} \end{aligned} \tag{3}$$

where L is the amount of grays scales in the input image $f_{M\times N}$. $f^x_{\max}$ and $f^x_{\min}$ are respectively the maximum and minimum of $(f(i,j+1), f(i,j-1))$. $f^y_{\max}$ and $f^y_{\min}$ are respectively the maximum and minimum of $(f(i+1,j), f(i-1,j))$. For example, we assume the gray scales of pixels at position $(i,j), (i,j-1)$ and $(i,j+1)$ are respectively 120, 130 and 100 for an 8-bit image. $GV^x_{(i,j)}$ and corresponding index of each element are shown as:

$$\begin{matrix} GV^x_{(i,j)} & [0 & \cdots & 1 & \cdots 1 \cdots & 1 & \cdots & 0] \\ index & 0 & \cdots & 101 & \cdots k \cdots & 130 & \cdots & 255 \end{matrix} \tag{4}$$

The total number of ones in this vector reflects the gradient value of point (i,j) and the position of these ones corresponds to the gray scale range at which this scalar gradient occurs. Similarly, $GV^y_{(i,j)}$ can also be calculated.

For the whole image, we add GV^x and GV^y at all positions together and define the new AGH as:

$$\begin{aligned} &AGH = fix((A+B)/2) \\ &A = \sum_{i=1}^{M}\sum_{j=1}^{N} GV^x_{(i,j)},\ B = \sum_{i=1}^{M}\sum_{j=1}^{N} GV^y_{(i,j)} \end{aligned} \tag{5}$$

where $fix(x)$ is a function doing rounding, which rounds x to the nearest integer.

The pseudo-code of obtaining the AGH is shown in Fig. 1. $\max(x,y)$ and $\min(x,y)$ denote the maximum and minimum of x and y respectively.

The traditional intensity histogram counts the pixel population of each intensity, which only contains the intensity information. Our AGH, on the other hand, contains both the gradient and intensity information of image. The detail explanations are given as follows:

① AGH is related to the gradient of every pixel, This point of view could be supported by the definition of GV^x and GV^y in (3). Moreover, the mean of all elements in our AGH can measure the gradient strength of image, which actually equals to MAG defined in (1). From the definition of AGH, we know that AGH is also of size $1 \times L$ and can be represented by $AGH = [h_0, \ldots, h_{k,\cdots}, h_{L-1}](k = 0, 1, \ldots, L-1)$. According to (2) and (3), we have

$$|G_x(i,j)| = \sum_{k=1}^{L} GV_x(i,j),\ |G_y(i,j)| = \sum_{k=1}^{L} GV_y(i,j) \tag{6}$$

Comparing (1) with (5) and (6), we have

$$MAG = \frac{1}{MN}\sum_{k=0}^{L-1} h_k \tag{7}$$